NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SIMULATING AN ISOCHRONAL SCHEDULED INSPECTION SYSTEM FOR THE P-3 ORION

by

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September 1998

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REPORT DOCUMENTATION PAGE	Form approved OMB No. 0704-188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE September 1998	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE
SIMULATING AN ISOCHRONAL SCHEDULED INSPECTION SYSTEM FOR THE P-3 ORION

5. FUNDING NUMBERS

6. AUTHOR(S)
Jones, Jeffrey A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
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14. SUBJECT TERMS
Aviation, Scheduled Maintenance, Simulation, Java, Isochronal

15. NUMBER OF PAGES 76

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF THIS ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18

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SIMULATING AN ISOCHRONAL SCHEDULED INSPECTION SYSTEM FOR THE P-3 ORION

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1998

ABSTRACT

The purpose of this thesis is to explore potential challenges facing the implementation of an Isochronal Scheduled Inspection System (ISIS) for the United States Navy's P-3 Orion. Implementation of ISIS, which is based solely upon calendar time, has been proposed to replace the present system of scheduled inspections that are based upon both calendar time and flight hours. The United States Customs Service and the Royal Netherlands Navy have successfully fielded the ISIS program and demonstrated that the concept works when implemented on a small scale. It is not known however, how well the program might work when applied to a larger organization. This thesis obtains insights into potential troubles arising from implementation of the ISIS program by building and analyzing a simulation model. The model's output includes the number of times aircraft induction dates are rescheduled, and the number of days that scheduled aircraft induction dates are changed by. The analysis provides a measure with which to gauge the difficulty of implementing the ISIS program in the U.S. Navy.

THESIS DISCLAIMER

The reader is cautioned that assumptions made with regard to the data used in this research are those of the author. Furthermore, although every effort has been made to ensure that the computer simulation program is free of computational and logical errors, it cannot be considered validated. Any application of information obtained from this thesis without further validation is at the risk of the user.

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EXECUTIVE SUMMARY

The cost associated with maintaining a fleet of aircraft is substantial. Preventive maintenance has substantial impact on the service life and operational availability of Naval aircraft. Preventive maintenance, also called scheduled maintenance, repairs aircraft components prior to catastrophic failure and exacts the greatest use from parts in service. The methods by which aircraft are scheduled for regular inspections have changed over time.

The current process used for determining when the P-3 Orion should be inducted for scheduled maintenance is based upon either the number of days passed since the previous inspection, the number of flight hours which an aircraft has accrued, or both. This process is logical in that the intent of the program is to follow inspection intervals that accurately capture the rates at which component degradation occurs. Some components wear more rapidly when the aircraft is flying, others wear at the same rate whether or not the aircraft is flown.

An alternative to this mixed calendar and flight hour process is a program in use with the United States Customs Service and the Royal Netherlands Navy. The program is called an Isochronal Scheduled Inspection System (ISIS). Under ISIS the decision to induct aircraft for scheduled maintenance is based solely on calendar time. The benefits of ISIS can be realized in a reduction in the number of scheduled maintenance man-hours per flight hour. The number of unscheduled maintenance man-hours per flight hour has also been shown to decline under ISIS. The structured format of the calendar induction process results in a simpler long range maintenance schedule that allows for more

accurate planning by both operational and maintenance planners. The long-term benefits of ISIS are increased operational availability of aircraft and reduced cost for repairs arising from better condition of the aircraft.

The objective of this study is to estimate the impact that squadron aircraft transfers (which are unique to the U.S. Navy) have upon an ISIS program. The impact is expressed in terms of the number of changes that the ISIS schedule must undergo, and the amount of those changes, measured as the number of days deviated from the original schedule. The basis for this study is the P-3C Orion, the only land-based, long-range maritime patrol aircraft in the U.S. Navy's inventory. A computer model was designed to simulate the ISIS scheduling plan when implemented among three squadrons that execute inter-squadron aircraft transfers. The model emulates squadron aircraft transfers arising from deployment operations. Each simulation run is conducted using a generic test scenario. An evaluation of the impact that these transfers have on the success of the ISIS program provides insight into the potential challenges facing a fleet-wide implementation of ISIS. The measures of effectiveness used in the comparison are number of times aircraft induction dates are rescheduled, and the number of days by which scheduled aircraft induction dates are changed.

The results of the simulation show that an ISIS program can be difficult to implement in an environment where aircraft transfers occur regularly. The results also show that the squadron composition, number of aircraft and update version, have significant effects on the execution of the maintenance schedule. These effects include bringing aircraft in for maintenance earlier than required and grounding aircraft until maintenance can be performed. The results of this model can provide decision-makers

with valuable insight into the difficulty to be faced if implementation of the ISIS concept goes forward into the current operational environment.

ACKNOWLEDGEMENT

The author would like to acknowledge the financial and technical support of the Naval Air System Command, PMA-290, for assisting with the development of this thesis.

The author wants to thank Captain Robert M. Hagan, USMC, for going beyond the call of duty assisting the author with proofreading this thesis.

I. INTRODUCTION

To reduce the potential failure of a component, maintenance is an important process that must be followed diligently. This is especially true in aviation maintenance, where the potential consequences of component failure are particularly dire. Routine scheduled maintenance plays a key role in this process. By monitoring the condition of parts and equipment throughout an aircraft's life, material degradation can be tracked and corrected. Aviation maintenance methods have been at the forefront of maintenance practices, and they continue to evolve. Ongoing efforts are directed toward developing scheduled maintenance programs that efficiently utilize available time and money, while also ensuring aircraft are maintained to a high readiness standard. Recently a change has been proposed to the scheduled maintenance program for the United States Navy's P-3C Orion. In August of 1997 the Naval Air System Command presented a proposal for an Isochronal Scheduled Inspection System (ISIS). Commander Patrol Wing Five was tasked to conduct validation and verification of the ISIS concept over an eighteen-month period beginning in April of 1998. Patrol Squadron Ten was selected to implement the test program [Ref. 1].

The P-3C is a land-based, long-range maritime patrol aircraft that entered the Navy inventory in 1962. It has undergone one designation change (P-3V to P-3) and three major models: P-3A, P-3B, and P-3C, the latter being the only model now in active service [Ref. 2]. Additionally, the P-3C has gone through several upgrades. Currently there are three versions in use by the active duty patrol squadrons (VP). These are the update three (UIII), update two and a half (UII.5), and update two (UII) aircraft.

Presently there are no plans to replace the P-3 aircraft prior to the year 2015. In order to ensure this aging fleet of aircraft can continue to perform their missions, it is imperative that maintenance of the aircraft be given continued attention.

For this thesis a simulation model was created using the organization structure of the P-3 squadrons assigned to the Naval Air Station in Brunswick, Maine. These squadrons operate under the command of Patrol Wing Five. The goal is to model the Isochronal Scheduled Inspection System when instituted at the Wing level, where the Wing is comprised of three squadrons. The model's objective is to estimate the extent of the impact that squadron aircraft transfers have on the ISIS scheduling process. A second objective is examining potential methods of scheduling aircraft in order to increase the effectiveness of ISIS. Demonstrating potential difficulties that implementation of the ISIS program is likely to encounter is the overall purpose of this thesis. This effort can assist planners working to refine exactly how ISIS will be implemented.

II. AIRCRAFT MAINTENANCE

The first section of this chapter is a brief description of the commercial aviation maintenance concept. This description is germane because military aviation maintenance has benefited significantly from commercial practices. Subsequent sections describe the present P-3C Scheduled Maintenance concept, Isochronal Scheduled Inspection System (ISIS) and other significant considerations for implementing an aircraft scheduled maintenance program.

A. COMMERCIAL AVIATION MAINTENANCE

It is easy to understand the imperative for the airline industry to correct faults in aircraft prior to the point of component failure. If the airline industry were content with fixing a part following its failure, the result would be more frequent loss of aircraft and lives due to mishaps.

Rather than bringing aircraft in occasionally for a complete overhaul, the commercial aircraft industry follows a system of inspections and repairs. The timing of these inspections is critical. Out of the need for an efficient inspection cycle, the commercial airline industry developed a practice called Reliability Centered Maintenance (RCM) during the early 1970's. "RCM centers on the probability that an item will survive without failure to a specific operating age, under specified operating conditions, if maintained under a strict schedule." [Ref. 3]. The ability to reasonably predict the useful life of a component allows planners to determine the most efficient aircraft maintenance schedule.

B. P-3C AIRCRAFT MAINTENANCE

The Lockheed P-3 Orion aircraft has been in service with the United States Navy since the early 1960's. Over time, procedures for performing scheduled maintenance on the aircraft have changed as better methods have been developed and incorporated. Scheduled maintenance periods consist of an inspection cycle and a repair cycle. They are presently initiated following a prescribed number of days and/or a specified number of flight hours.

When the P-3 was introduced into the fleet in 1962, the aircraft scheduled maintenance program was based upon a calendar inspection concept that consisted of inspecting the entire aircraft during each inspection cycle. This philosophy was maintained throughout the 1960's and into the early 1970's. Over this span of time the inspection interval, i.e., the time between inspections, increased from nine weeks to twenty-six weeks by 1973 [Ref. 4].

Early in the 1970's, representatives from both commercial airlines and aircraft manufacturers, known as Maintenance Steering Group-2 (MSG-2), developed several advanced maintenance concepts. The P-3 was one of the first Navy aircraft to incorporate concepts generated by the MSG-2. "The Navy recognized inadequacies in their system and looked elsewhere to improve aircraft maintenance. Inquiries into commercial airlines practices resulted in a NAVAIR (Naval Air Systems Command) request for Lockheed to investigate the feasibility of adapting the L-1011 TriStar type maintenance program to P-3 Orion aircraft." [Ref. 4]. One program implemented in 1974, referred to as the P-3 Improved Maintenance Program (IMP), changed the P-3 scheduled maintenance plan from the calendar concept to one based strictly upon phased flight hours. The total

inspection interval under the IMP was set at 800 hours, divided into four 200-hour phases. In 1977, the inspection interval was extended to 1200 hours. By this time though, a primary indicator of aircraft material condition, maintenance man-hours expended per aircraft flight hour, had crept up to the level that was required under the old calendar inspection program [Ref. 4]. This was a signal that the program was not working as well as had been expected.

Over time additional maintenance requirements had been added to these scheduled inspections, the result being a "duplication of all aircraft zones inspected and over 100 access panels opened. This duplication results in a detailed inspection of most aircraft zones on an average of once each 70 days, or 115 flight hours. Most of this duplication has occurred as a result of aircraft utilization rates being significantly lower that what was used as a base during the original analysis." [Ref. 4]. Items which were originally determined to be flight hour dependent, but over time had proven to be both flight hour and calendar sensitive, needed to be handled by a special inspection. The "special inspections are undesirable, and are to be avoided unless absolutely necessary." [Ref. 4].

C. ISOCHRONAL SCHEDULED INSPECTION SYSTEM

The P-3 assistant program manager for logistics at the Naval Air Systems Command is in the process of testing a maintenance program called ISIS (Isochronal Scheduled Inspection System). ISIS is based entirely upon calendar inspections. This maintenance plan calls for strict adherence to aircraft inspection dates to realize savings in maintenance hours expended. Under ISIS an aircraft is inspected for one week.

Immediately following the inspection, two weeks are made available for correcting discrepancies that require attention. The aircraft is then returned to service for thirty-two weeks until the next inspection arrives. As with the current program, the aircraft continue to have a daily inspection, and a 28-day special inspection [Ref. 5]. Some of the ISIS goals are to reduce annual scheduled inspections, reduce unscheduled maintenance man-hours, and improve material condition of the aircraft [Ref. 1].

The ISIS maintenance program is currently being used by the United States Customs Service (USCS), and the Royal Netherlands Navy (RNLN). Both organizations fly the P-3 Orion aircraft in operating environments similar to the US Navy's. Under ISIS, the USCS and RNLN have realized approximately five-percent reductions in the number of man-hours spent performing scheduled maintenance [Ref. 1]. As a greater period of uninterrupted maintenance is performed, the condition of the aircraft has been shown to improve. This is reflected in reductions of over thirty percent in the number of unscheduled maintenance man-hours expended [Ref. 1].

D. COMPARISON OF THE CURRENT PROGRAM WITH ISIS

The proposed calendar program contrasts with the current system because under the present system an aircraft is brought in for periods which last four to five days [Ref. 6], and then is returned to service until either the next calendar inspection arrives, or a flight hour limit is met. The difference between the two programs, shown by the frequency of induction for maintenance, is illustrated in Figures 1 and 2. These figures show that under the current program aircraft are inducted for maintenance more frequently than under an ISIS program. Under the current system the aircraft are inducted

for calendar required inspections (white blocks) and flight hour requirements (black boxes). The flight hour inspections are estimated based upon expected flight rates. Increasing or decreasing the number of hours that an aircraft is flown will cause a shift in the induction date of a flight hour required inspection. If ten hours were remaining before an aircraft was inducted, the aircraft could be flown on five two hour

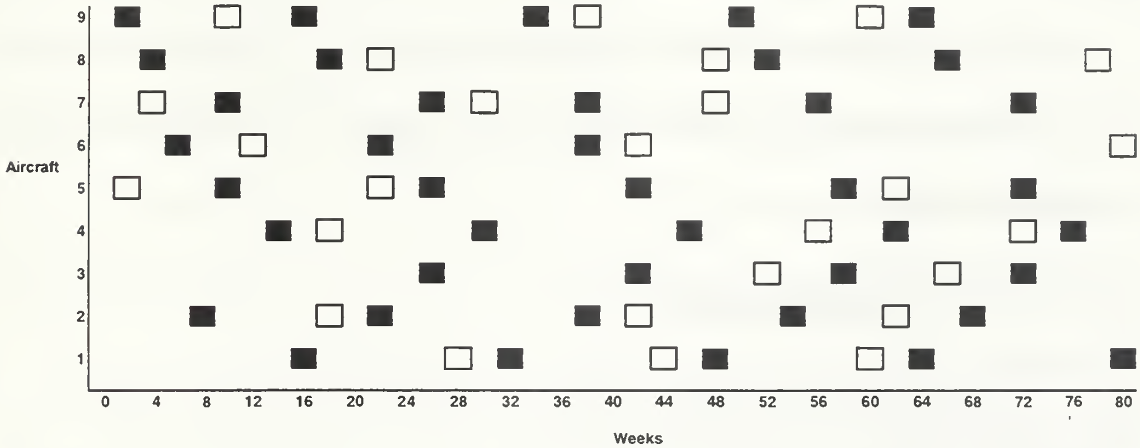

Figure 1. Present Calendar and Flight Hour Induction Cycle

missions. This might take a week to occur depending upon how often the aircraft was scheduled. Alternatively, the aircraft could fly a single ten hour mission, and thus need induction following the flight.

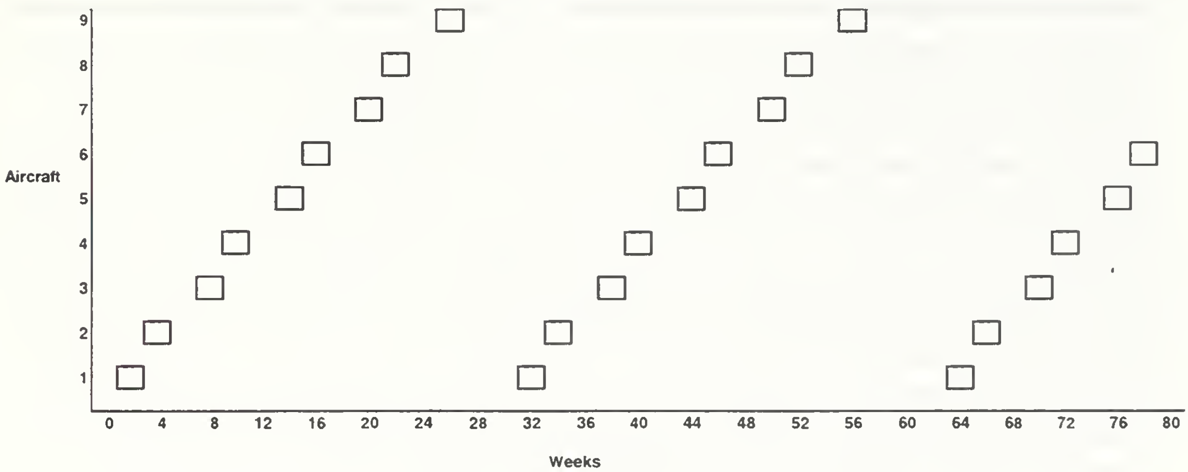

Figure 2. ISIS Induction Cycle

An additional benefit of the ISIS program is that it allows a person scheduling aircraft for missions, or other events, to more easily determine when the aircraft will be available. Because aircraft induction occurs less frequently and follows a rigid process, it is much easier to determine when an aircraft is going to be available to fly.

E. OTHER CONSIDERATIONS

Two significant issues that may impact the effectiveness of the ISIS within the U.S. Navy are organization of the U.S. Navy, and the manner in which VP squadrons deploy and operate.

1. Naval Organization

In contrast with the USCS and RNLN, a key challenge for the U.S. Navy is managing the large number of aircraft in its inventory as well as the number of entities controlling those aircraft. The USCS and the RNLN each have a single squadron of P-3 aircraft, numbering from nine to thirteen aircraft. The U.S. Navy has roughly 235 P-3 aircraft in inventory. Within the active duty squadrons there are 120 P-3 aircraft distributed among twelve squadrons [Ref. 7]. These squadrons rotate through overseas deployment sites, which in some instances have indigenous aircraft configured with mission specific hardware that remain at that location. The result is a requirement to transfer aircraft when two squadrons rotate through a deployment site. Each squadron has it's own maintenance department, and the aircraft in its custody follow that particular squadrons maintenance schedule. When a transfer of aircraft between squadrons is required, conflicts between the maintenance schedules can arise.

Since the USCS and RNLN each have one relatively small squadron, implementing an ISIS program within such an organization is an easier task than the U.S. Navy will face, even when the aircraft operate in similar environments.

2. Aircraft Transfers

The transfer of P-3 aircraft between squadrons is unique to the U.S. Navy. In addition to the requirement to transfer the handful of special mission capable aircraft, there are other reasons for which transfers are performed. For example, when VP squadrons deploy, they are required to do so with only UIII models. This requirement exists despite the fact that there are not sufficient UIII model aircraft available for each squadron to have a full complement of this model. As a result, aircraft are swapped with other squadrons to provide a deploying squadron with a full complement of UIII models.

Also, aircraft go through material upgrades, equipment upgrades, and phased maintenance periods. Each represents periods of time during which an aircraft is removed from service at the squadron.

Under ISIS the squadron scheduled maintenance program becomes a continuous cycle. Aircraft enter maintenance and then depart, to be replaced by the next aircraft in line. Once maintenance is complete on an aircraft it goes to the back of the line. Each aircraft has a place that it holds, and no two aircraft can occupy the same position in the cycle. Swapping aircraft between squadrons presents a problem because an aircraft that is brought into a squadron will most likely not be scheduled for inspection at the same time as the aircraft that was transferred out. The departing aircraft creates a vacancy in the cycle that stretches over a particular period of time. The aircraft that is transferring into

the squadron arrives with a maintenance induction date set by the squadron it detached from. If the newly arriving aircraft has an induction date that is the same as the departing aircraft, the transfer of aircraft is seamless. The new arrival fills the void in the maintenance cycle created by the departing aircraft. But, if the newly arriving aircraft is scheduled for induction at a different period of time, conflicts can arise. The new arrival may be scheduled for maintenance during the same time as an aircraft already with the squadron. Because no two aircraft can occupy the same position within the maintenance cycle, to fill the void in the cycle, the squadron may need to bring an aircraft in for preventive maintenance sooner than is necessary. A more serious problem arises when the arriving aircraft requires corrective maintenance before the open period in the maintenance cycle. If the available period of open time falls after the aircraft's induction date, the aircraft then must have its maintenance delayed. This situation could potentially ground an aircraft, until the time for performing maintenance is available. Figure 3 illustrates the three possible cases that can arise when an UII or UII.5 aircraft is removed from the squadron and a UIII replacement arrives.

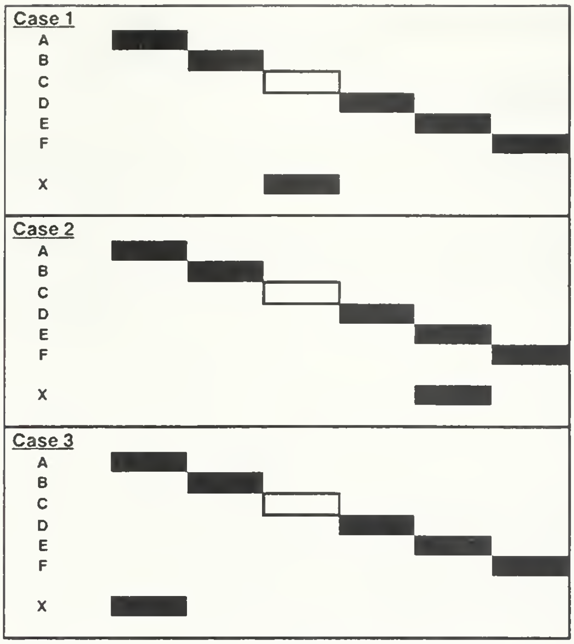

Figure 3. Three possible cases following an aircraft transfer

Case one shows the new arrival, aircraft X, filling the maintenance slot just vacated by the departing aircraft C. The open block indicates the departing aircraft's maintenance slot. The new aircraft requires maintenance performed during the time indicated by the dark box on the bottom row. The second case illustrates how the aircraft could have maintenance done early, while the third shows an aircraft being brought into the squadron, and then possibly being grounded while it awaits maintenance.

The ISIS program illustrates the evolution of maintenance efforts within the aviation field. The smooth transfer of civilian maintenance practices to military organizations is not assured. The success of the ISIS program with some military and government organizations does not mean the program will be successful with the U.S. Navy. Closer study of the ISIS program is needed before going forward with fleet-wide implementation of ISIS. This thesis addresses one issue concerning the implementation

of an ISIS program. The next chapter will discuss the methodology used to model aircraft maintenance under ISIS.

III. METHODOLOGY

This chapter describes the concept and development of the model used to simulate the scheduled maintenance and aircraft transfer processes. Later chapters will expand in detail on the simulation's formulation.

A. SIMULATION

Use of the simulation is to bring attention to possible challenges facing the implementation of ISIS for the P-3 Orion community. The simulation models the scheduled maintenance process applicable to a single P-3 Wing comprised of three Orion squadrons.

The objective of the ISIS maintenance program is to improve the condition of the aircraft and increase aircraft mission availability. Once aircraft in a squadron are assigned maintenance periods, they should be inspected and repaired as planned. The simulation implements decision rules designed to overcome conflicts that arise in the scheduling process with an aim toward the efficient scheduling of aircraft for maintenance.

The following sections describe elements relevant to this scheduling simulation.

1. Model Fidelity

To provide useful results, it is important to attempt to capture the way aircraft are scheduled for maintenance. This is accomplished by recreating the situations that confront decision-makers and the mechanisms used to execute decisions. Unfortunately, attempting to recreate all of the complexities of the real process leads to a prohibitively

large programming task. For the purposes of this evaluation, the simulation only needs to give general indications of potential problem areas rather than exceedingly fine detailed results. Therefore, the model focuses on the primary factors that drive, and impact, the scheduling process. The result has been the construction of a smaller, relatively simple model.

This simulation is built around a scheduling model. The capacity to handle scheduling conflicts within a squadron, and conflicts arising from a transfer of aircraft between squadrons have been the main areas of attention. Assumptions made and simplifications introduced to the scheduling process will be addressed later.

2. Scheduling Elements

The simulation model of a Wing level operation begins by defining the key elements, such as the number of squadrons the Wing will oversee. The simulation has been designed to handle any number of squadrons that the user wants to include. This thesis specifically analyzes three squadrons, such as are found at the Brunswick Naval Air Station, but the simulation may also be executed with any other situation at the discretion of the user.

The update versions of aircraft the squadrons deploy with, and the quantities that they have in inventory are additional components. The simulation recognizes UIII and non-update III (NUD) aircraft. Differentiating between UII.5 and UII aircraft is not necessary since both are replaced when a deployment occurs. Squadron composition of update versions, and aircraft numbers are not fixed. The number and types of aircraft possessed by a squadron fluctuates over time. As a result there is no fixed squadron

inventory for use as a typical case. The squadron composition employed was developed using information provided by Ref. 5.

3. Scheduling Times

Other considerations are the timing and duration of squadrons' deployment and the procedures followed when squadrons rotate through deployment sites. The model analyzed in the thesis uses a six-month deployment length, although the user can define any deployment length. Typical VP squadron deployments are between four and a half months to six months. The squadrons in the simulation rotate through deployments in turn.

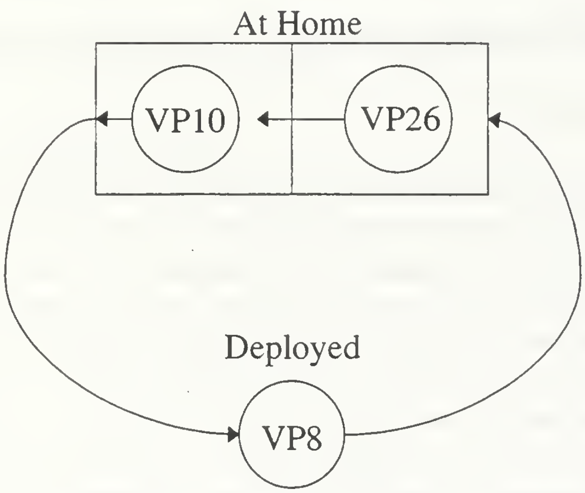

Figure 4. Squadron deployment rotation

Figure 4 illustrates the following example of a three-squadron rotation consisting of VP8, VP10, and VP26. To begin, VP8 is deployed overseas, while VP10 and VP26 are at home in Brunswick. VP10 deploys and VP8 returns to Brunswick. When VP10s deployment ends they are relieved by VP26. Finally, VP8 relieves VP26, restarting the

cycle. This roughly approximates the deployment cycle and operational tempo of the VP squadrons within a VP Wing.

How often the aircraft are inducted for routine maintenance and the amount of time they are worked on while in for maintenance are functions of the ISIS program. The ISIS program prescribes that aircraft be inducted every 224 days. Up to three weeks are allocated for performing inspections and maintenance on the aircraft. The entire three weeks may not be required to perform maintenance. However, the scheduling process within the simulation plans for the entire three weeks, since it will not be known in advance if an aircraft will need the entire period until it is being worked on. The capability to have aircraft in for maintenance for a varying length of time has been incorporated into the simulation, but it has not been utilized. As a result aircraft use the entire three-week time.

Tolerance for deviations from the schedule is an important part of the scheduling process. The simulation implements the ISIS window of plus or minus three days for inducting an aircraft for maintenance. This window is referred to as the grace period. Inducting an aircraft earlier than the grace period results in a re-baselining of the aircraft. This means that the induction date of the aircraft is updated to the new date on which the aircraft begins maintenance. Re-baselining results in a loss of efficiency within the ISIS program. This is because the aircraft has maintenance performed earlier than is required, and thus, there is a loss of time that the aircraft could have been flying.

Bringing the aircraft in late also re-baselines, although this is a more serious condition because the aircraft is grounded until maintenance is performed. When the aircraft exceeds the three-day window around the scheduled induction date, because

required inspections have not been performed, the safety of the plane's crew is compromised. Thus the aircraft is grounded from flying until the inspections are carried out.

Unused time periods when maintenance is not being performed allow for some flexibility in the program. The ISIS schedule is 224 days. A squadron that owns nine aircraft will use 189 of those days performing maintenance, if the entire three weeks are spent working on each aircraft. This means that over the course of thirty-two weeks there will be thirty-five days during which no maintenance is scheduled. This free time could be used to shuffle the schedule or adjust for problems that arise. The simulation does not attempt to capitalize on this time to prevent conflicts from arising. It does, however, attempt to utilize any free time available to resolve a conflict if one occurs.

4. Transfer Requirements

There are a number of reasons for which an aircraft might be removed from a squadron. When a deployment occurs, the NUD aircraft are transferred out, to be replaced by UIII models. Aircraft also go through equipment upgrades, and the aircraft itself may undergo structural upgrades. Both of these can result in an aircraft being removed from the squadron for extended periods of time. One benefit of the ISIS program is its allowance for the scheduling of these upgrades in a manner that does not interfere with the aircraft maintenance requirements. By knowing when an aircraft will be due for maintenance, several months in advance, it is possible to schedule the aircraft for periods of absence which do not cause conflicts with the maintenance requirements.

Aircraft also go through Phased Depot Maintenance (PDM) periods during which they are removed from the squadron for several months. This simulation only accounts for aircraft transfers that result from the occurrence of a deployment.

B. SCHEDULING LOGIC

There are two scheduling processes that this simulation addresses. One is the scheduling of aircraft for maintenance within a squadron. Once an aircraft is assigned to the squadron, it is necessary for the squadron to check when maintenance is due and to schedule that maintenance. Also, after an aircraft finishes maintenance, it must be scheduled for a future inspection, and the squadron must ensure that the future date does not conflict with other aircraft.

A second process involves the transfer between squadrons of several aircraft. In this case, there are a number of options that need to be considered. The goal is to select those aircraft that are best suited for transfer, based upon situational requirements.

The following two sections address how these scheduling processes are implemented within the simulation.

1. Squadron Scheduling

The scheduling of maintenance within a squadron is one of the simulation's functions. Each squadron performs maintenance on the aircraft for which it has custody. In the simulation each squadron has a maintenance department, referred to as the Hangar, that handles all of the squadron's aircraft maintenance.

When a scheduling conflict arises between aircraft within the squadron, the squadron must resolve the conflict and continue the maintenance cycle. Each squadron

has the capability to schedule an aircraft for maintenance, have that aircraft go through a maintenance period, and then reschedule the aircraft for a future maintenance period. The squadron is also tasked with resolving internal scheduling conflicts. The squadron additionally needs the capacity to deal with aircraft transfers. When an aircraft is added to the squadron, it is necessary to ascertain when that aircraft is next scheduled to have maintenance performed. The squadron evaluates the current maintenance plan and schedules the aircraft for maintenance when it is due, or if a conflict arises, checks for an alternate time to perform maintenance. This alternate time is chosen as close to the original schedule as possible. If no convenient time is available within the scheduling scheme, the squadron then looks to assign a day for maintenance whenever a day is made available. If this occurs, it means that the aircraft could be grounded for a period of time, if the rescheduled date falls after the originally scheduled day. The decision making process follows a procedure as depicted in Figure 5.

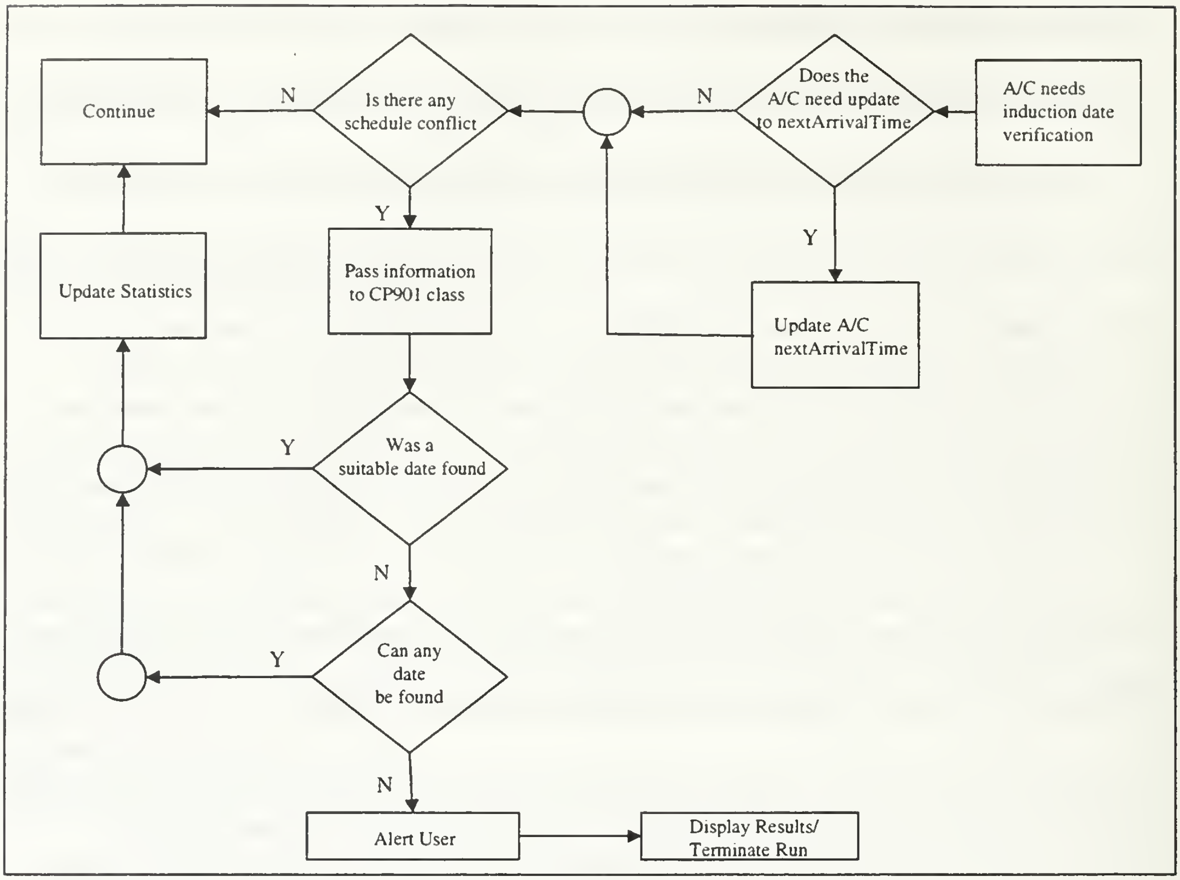

Figure 5. Evaluation of aircraft induction date

2. Inter-Squadron Transfers

Assigning aircraft to one of a variety of periods is one of the primary challenges to implementing a maintenance program in consonance with the ISIS. Developing a maintenance program that remains faithful to the ISIS schedule results in the assignment of aircraft, from a pool of available aircraft, to a specific maintenance period, when multiple periods are available. Ideally, this should be done with a minimum amount of adjustment to existing maintenance plans. This section describes the development of a model for optimizing the selection of aircraft to be assigned to a deploying squadron. The collection of algorithms used to determine the optimal assignment of aircraft to maintenance periods, within the deploying squadron, is referred to as the OptimizePool.

The objective for the code within OptimizePool is to select the required number of aircraft, and assign periods for maintenance to those aircraft while minimizing the absolute deviation from the date the selected aircraft had been already been assigned for maintenance.

Because assigning aircraft to the squadron that is returning from deployment is not considered critical, OptimizePool only determines the optimum assignment of aircraft to the deploying squadron. The returning squadron receives the NUD aircraft from the deploying squadron regardless of when maintenance is due. This was done to ensure a deploying squadron received the priority for minimizing the disturbance to its maintenance cycle, as the returning squadron will have a less demanding schedule and be more capable of accommodating variations in the maintenance schedule.

When a squadron deploys, it is required to do so with all UIII aircraft. Therefore any NUD models are removed from the squadron's inventory. The returning squadron makes available for transfer to the deploying squadron all of its UIII aircraft to fill vacancies in the deploying squadron's inventory. Because the deploying squadron has some UIII models, and the availability of open periods within the maintenance cycle is limited, some of the UIII models owned by the returning squadron are not capable of filling the gaps in the deploying squadron's cycle. Prior to calling OptimizePool, the program reduces the potential number of aircraft to the candidates capable of fitting into the deploying squadron's schedule. The program then looks for free time periods in the deploying squadron's maintenance cycle. Next it determines if there are any time periods that cannot be used by any of the available aircraft. The reason for this situation is that all of the UIII aircraft from the returning squadron could be due for maintenance before an

available period of time with the deploying squadron. Since the time period is too late to be used by any of these candidate aircraft, the maintenance period is discarded as a potential maintenance period. The discarding of aircraft and maintenance periods is done to reduce the number of potential assignments that must be analyzed.

Having eliminated ineligible aircraft and maintenance periods, the remaining aircraft and maintenance periods are passed to the optimizing routine along with the number of aircraft required by the deploying squadron. If more aircraft are needed than can be supplied, the program returns a warning stating that there are not enough aircraft available. In practice, this should never happen because the deploying squadron will only need to replace one or two NUD aircraft while the returning squadron is completely composed of UIIIs.

If there is not enough free time available to perform maintenance on the required aircraft, the program will also return a warning that there is insufficient available time. This could arise if one of the NUD aircraft removed from the squadron was next due for maintenance at a late period. If all of the candidate aircraft to replace that particular aircraft have requirements for maintenance before the vacated time period, the time period would not be available to any of the potential aircraft.

The decision framework for selecting aircraft and assigning maintenance periods can easily be represented with a network model. The cost associated with traversing the network is the number of days the selected aircraft deviates from the original maintenance induction date. An ideal scheduling situation would be one in which each aircraft selected fit directly into the maintenance cycle, and thus the deviation is zero. The following example illustrates this point. If the aircraft being removed from the squadron

was due for maintenance on day ten, and one of the aircraft available for replacement into the squadron was also due for maintenance on day ten, the transfer of these two aircraft would be seamless. When the day an aircraft is inducted must be changed, every day from the original induction date leads to a degradation of the ISIS schedule. However, when a block of free time is available for maintenance that is longer than an aircraft requires for maintenance, options become available for inducting the aircraft. Ideally, the selected date would bring the aircraft in close to its scheduled date. If the free period was long enough, two or more aircraft could potentially be scheduled within that block of time. As multiple aircraft are available for selection, and the number of potential days to induct those aircraft increases, the possible scheduling combinations increases as well.

Figure 6 is a graphical depiction of this as a network model.

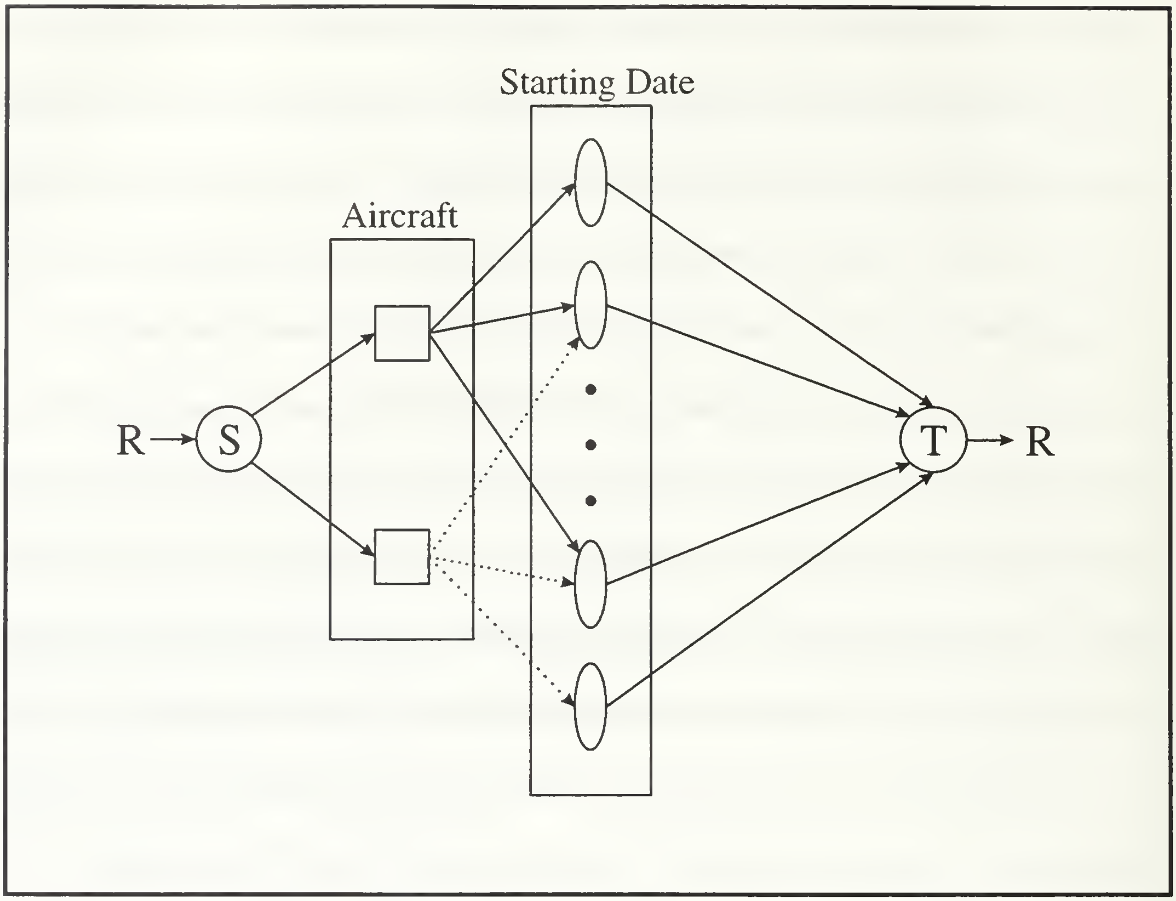

Figure 6. Aircraft Selection as a Network Model

The source node, S, receives the supply of flow, R, that is equivalent to the number of aircraft being requested by the deploying squadron. This is the number of UIII aircraft that are needed to fill the inventory. The next column of nodes, aircraft, represents the aircraft available to choose from when filling the deploying squadron's demand. The third column, starting date, represents all of the starting days available for scheduling aircraft to begin maintenance. Not every starting day is available to every aircraft. As shown in the diagram, the upper aircraft can use any day, except the bottom-most date while the lower aircraft can use any date, except the uppermost. Finally, each start date is joined to the terminating node, T.

In this formulation, the maximum amount of flow that can pass over any arc has a value of one. This corresponds to at most one aircraft being passed along a particular arc. The minimum amount of flow is zero to prevent any negative flow from occurring.

At each aircraft node a flow balance constraint is imposed which states that the amount of flow entering the aircraft node must be equivalent to the amount that exits the node. The only arcs which have a non-zero cost associated with them extend from the aircraft node to the starting date node. This cost is the number of days that the potential starting date deviates from the aircraft desired starting date. For instance, if the aircraft was due for maintenance on day thirty, and the starting node was day thirty-five, the deviation would be five.

The OptimizePool code does not make a differentiation between early and late starting times. Therefore an aircraft would be penalized the same, in cost, for arriving five days early, as it would for arriving five days late. In practice, a scheduler would prefer to bring the aircraft in five days early, since five days late would mean the aircraft had been grounded. The difficulty is in assigning a penalty to a late induction. There is no rule that establishes at what point a given number of days late become more attractive than a number of days early. A natural question is whether it is better to bring an aircraft in twenty days early, or five days late. The model attempts to minimize the number of days deviated from the planned induction date regardless of whether or not the date was early or late.

At the date nodes, the amount of flow entering the nodes must be equivalent to the amount that is leaving. Additionally, the amount of flow departing any date node and any others within twenty-one days following the date of that node must sum to one. This

constraint prevents different aircraft from being assigned to overlapping periods of time. If the constraint were not included, one aircraft could be scheduled for day twenty, and another could be scheduled for day thirty. In this case, at day thirty, and until day forty-one, both aircraft would be in for maintenance at the same time, which is impossible.

In theory this is an integer-programming problem. OptimizePool calls upon a Linear Programming (LP) solver that is also a Java coded algorithm [Ref. 10]. Because the problem is being solved with a linear programming solver, there is the potential that it could return non-integer values. To minimize this possibility the constraint equations are set up to try and force an integer solution. While there is no way to be certain that the LP solver will return an integer value, in practice the results have always been integers. Further, the simulation is constructed such that the only solutions recognized are those that are integers.

The LP solver returns the amount of flow allocated over each arc. By determining which arcs have a flow value of one, and ascertaining which nodes those arcs join, it can be determined which aircraft are selected for transfer, and the date to which they should be assigned for maintenance. The formulation of this problem can be found in Appendix B.

IV. SIMULATION DESCRIPTION

A. ASSUMPTIONS

Creating a scenario upon which to base model runs involved making some assumptions about the size and composition of the squadrons involved. Because the number of aircraft in a squadron's inventory is not constant, an assumed range from seven to nine aircraft for a non-deployed squadron and nine to ten aircraft for a deployed squadron was used.

The type of aircraft in a non-deployed squadron also varies. The simulation involves three squadrons; two at the home base and one deployed. The assignment of two NUD aircraft to one home base squadron and one NUD aircraft to the other captures this variation in composition. The deployed squadron consists solely of UIII aircraft.

Along with these assumptions, several simplifications have been applied to the actual scheduling problem in order to facilitate creating the simulation.

1. Maintenance Period

The analysis that was performed to create ISIS determined that three weeks of maintenance should be allocated for an aircraft. The first week allocated for inspection and the following two weeks for repairs. It is unrealistic to believe exactly three weeks will be used by each aircraft. In practice, situations will arise where an aircraft requires a different amount of time, either less than or more than the entire period. This could affect the induction date of follow-on aircraft. Because ISIS has not yet been implemented, no data exists on the average time for maintenance. In the future, when data is available, it

may be valuable to investigate the effect that a variable maintenance period has on the ISIS program. This investigation only focuses on evaluating the prescribed three-week interval.

2. Stand Down Period

The simulation is built with the simplification that the maintenance conducted by a squadron going onto deployment, or returning from a deployment is uninterrupted during the transition. Maintenance continues uninterrupted even as a squadron transfers to a deployment site or returns to its home base. Normally, during the time leading up to a deployment, the squadron would begin to prepare material for transfer to the deployment site. Equipment would be packed, which would result in the squadron being incapable of performing maintenance. A stand-down period ranging from three to seven days would arise during which time major aircraft maintenance is not performed. A similar situation would occur when the squadron returns from a deployment. The simulation simplifies this situation by allowing maintenance work to continue throughout the transfer process.

3. Upgrade and Maintenance Transfers

Occasionally, there are equipment improvements and aircraft modifications that are applied to the squadron's aircraft. The occurrence of these upgrades can result in an aircraft being removed from the squadron for an extended amount of time. The length of time the aircraft is removed varies with the amount of modification required. Additionally; aircraft are scheduled for PDM, which last about 120 days. During this time, the aircraft is removed from the squadron and transferred to a depot level

maintenance facility. The scheduling of upgrades and PDM periods is specific to a particular aircraft. The scheduling of a particular upgrade can be affected by when that aircraft is available, for instance not on deployment. Because these situations can be scheduled around squadron deployment plans, the simulation does not account for the transfer of aircraft for upgrades or PDM periods.

4. Site Specific Hardware

Some P-3 aircraft have been equipped with special hardware for use in a particular theater of operation. In the Caribbean theater there are special Counter-Drug aircraft. The Mediterranean theater has aircraft equipped with Electro-Optical imaging cameras for use on reconnaissance missions. These specially configured aircraft remain in the specific theater. A squadron deploying to the theater takes custody of these aircraft. This means that these particular aircraft must be assigned to the arriving squadron. Forcing a squadron to accept particular aircraft increases the chance of a scheduling conflict. This aspect of the scheduling process has not been included in the simulation.

5. Single Wing Transfers

The simulation looks at the transfer process between three squadrons in the same Wing that rotate through deployments in turn. In practice, the transfer of one squadron's aircraft to an incoming squadron would be further complicated by the inclusion of a second Wing, that includes an additional three squadrons. Transfers between wings would result. This complication has not been included in the simulation.

B. INPUT

There are two types of input required to execute the simulation: user input and file input.

1. User Input to the Simulation

The user inputs the number of deployments to execute, which translates to the simulation's duration.

2. File Input to the Simulation

Primary input to the simulation is supplied through aircraft and squadron data files. These text files contain data used to create the individual aircraft and the separate squadrons. The aircraft files are given names that correspond to the aircraft bureau number and the squadrons are given names that represent which numbered squadron they are. For instance, an aircraft file would be named 161001; while a squadron file would be named VP10. Both file types are given the file extension type dat.

The aircraft data file contains nine fields of information. Descriptive text that is not to be read is prefaced with a pound sign (#). The fields are arranged as in Figure 7.

```
#Aircraft Data

#Model
NUD

#Bureau Number
159320

#Squadron Assigned To
26

#Air Station
Brunswick

#SRP Date
0

#AIP Date
0

#PID Date
182

#Last Inspection
98188

#Next Inspection
98197
```

Figure 7. Sample aircraft data file

The simulation does not currently utilize all of this information. The required entries are in bold case. The other entries are included for future expansion of the model. They should contain some information, not necessarily accurate, in order for the simulation to properly read all of the data.

The squadron data file contains a listing of all of the bureau numbers for aircraft that the particular squadron holds in inventory.

```
156509
157330
158207
158210
158568
158917
```

Figure 8. Sample squadron data file

Although there is no limit on the number of aircraft that a squadron can have assigned, there is a minimum requirement of one aircraft in the squadron. The squadron data file resembles Figure 8.

C. MODELED OBJECTS

The simulation was implemented in Java, using the Java Development Kit version 1.1.6, an object-oriented computer language. Object-oriented programming has at its foundation the concept of software objects that are modeled after real-world objects. That is, the software objects have a state and behavior. The software object maintains its state in variables and implements its behavior with methods. A collection of Java code that represents an object is called a class. This section describes the most significant objects (classes) developed for the simulation. The relationship between these classes is illustrated in Figure 9. The Wing class contains a Squadron class. The Squadron class contains an Aircraft class, etc. Execution of the simulation is handled with the software package Simkit [Ref. 11].

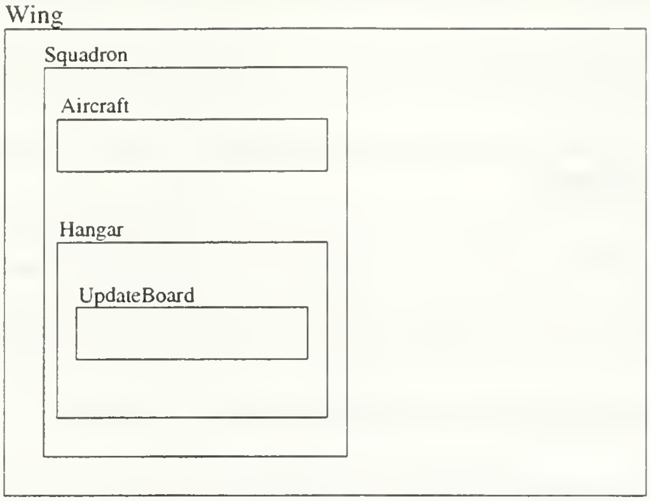

Figure 9. Relationship between significant objects

1. Wing

The Wing class acts as a container for the squadrons that fall under its control. It also handles the scheduling and execution of deployments for those squadrons. To create a squadron, the Wing class passes to one of its internal classes, the createSquadron class, the name of the squadron to create, such as VP10. The createSquadron class will return either the squadron it has created, or an error message, if no file matching the file name is located in the directory where the Wing class is residing. When a deployment occurs, the Wing, as well as the transfer of aircraft between squadrons, handles each squadrons change of status. The Wing contains several classes that are used to select the aircraft for transfer between the squadrons. The Wing then assigns aircraft and removes aircraft from the appropriate squadrons.

2. Squadron

The Squadron class contains information about a particular squadron. It also acts as a container for all of the aircraft that are maintained in its inventory. In addition, the

Squadron contains the Hangar and UpdateBoard classes. These handle the maintenance and scheduling of the aircraft.

3. Aircraft

The Aircraft class acts as a container for all data pertinent to an aircraft. Such as series type, bureau number, and squadron. It also maintains information about when maintenance was last performed, and when it is scheduled to next be performed. Additionally, the aircraft has functions that allow an external entity to retrieve and modify certain types of information.

4. Hangar

This class is used to simulate the movement of the aircraft through maintenance. When this class is created, it is passed all of the aircraft that the squadron has in inventory, and it schedules them for maintenance. It initiates and completes the maintenance on the aircraft and schedules the next arrival. When an aircraft is removed from the squadron, this class cancels any pending maintenance. When an aircraft is transferred into the squadron, it schedules maintenance for that aircraft. This class calls the UpdateBoard class to determine what date the aircraft will use for the next maintenance period.

5. UpdateBoard

The UpdateBoard acts as the schedule checker. This class checks for conflicts within the squadron maintenance cycle and reschedules the aircraft for future maintenance if the initially assigned date causes a conflict. If a conflict arises,

information is passed to the UpdateBoard's CP901 class that contains LogicUnit classes to search for an acceptable date to perform maintenance.

When changes are made, the UpdateBoard notifies it's StatKeeper class so that the necessary statistics can be updated.

D. SAMPLE RUN

The following description provides a tour of the process that occurs when the simulation is run.

To begin the simulation the Java class file TestISIS is executed. TestISIS creates a Wing and assigns to the Wing the number of deployments to carry out. When the Wing is first created, the number of deployments is set and then the squadrons that the Wing controls are created.

Each squadron is created by calling the createSquadron class, and passing to it the string representation of the file name of the squadron it is to create, for instance, VP10. CreateSquadron opens the data file corresponding to the given squadron. The squadron data file contains a listing of all of the aircraft that the squadron has custody of. The bureau numbers are used as the file names for the aircraft data files. The createSquadron class passes to the createAircraft class the name of each aircraft to create.

CreateAircraft then opens the data file for the aircraft with the passed bureau number. The data file is read, and the information is passed to an Aircraft. After the aircraft is created it is stored with any other aircraft, and then the container of aircraft is passed back to the createSquadron class. The createSquadron holds onto the container of

the aircraft. A method within the createSquadron class returns the container of aircraft when requested. These aircraft are then passed into the constructor of a Squadron.

When the squadron is created it also creates classes for it's own use. The squadron will primarily use its Hangar class.

The Hangar carries out the maintenance on the aircraft, and has a class called UpdateBoard that it uses to confirm the rescheduling of aircraft once maintenance is complete.

UpdateBoard contains the classes used in determining the appropriateness of a scheduled date. UpdateBoard also has classes for helping to determine alternate dates. The CP901 class is used to implement all of the logic applied when checking the validity of a date, and when attempting to find an alternate date.

A class called Segment is used to represent segments of time. For example, a period from day one to day twenty-one. An AircraftSegment is a special Segment class that also contains information about a particular aircraft. This class is used to represent the time during which the aircraft is scheduled to be worked on for maintenance.

When the Wing executes deployments, the AircraftRoulette class is used to determine which aircraft should be transferred into the deploying squadron. The AircraftRoulette class has methods to remove ineligible aircraft and maintenance periods, discussed previously in the section on inter-squadron transfers. After having done so, the remaining aircraft and free segments are passed to the OptimizePool class, as well as the requested number of aircraft to select for transfer. OptimizePool returns the selected aircraft, or returns a warning message if a selection can not be made due to a lack of aircraft or free maintenance time.

The aircraft that have been selected are returned to the Wing class for assignment to the deploying squadron. The Wing also retrieves the NUD aircraft from the deploying squadron and assigns them to the returning squadron.

The simulation then moves forward by performing the scheduled maintenance on the aircraft, until the next deployment occurs.

When the requested number of deployments have been carried out, or an unresolvable scheduling conflict arises, the simulation is stopped. All data collected to this point is written to data files, and summary statistics for each squadron a displayed. The number of deployments that were executed is also displayed.

E. GENERATION OF RESCHEDULES

A scheduling conflict either results in the rescheduling of an aircraft maintenance period, or termination of the simulation run. Termination would result if the conflict could not be resolved by the simulation's scheduling logic. The simulation begins with all aircraft scheduled for maintenance during time periods that do not conflict. Whenever an aircraft is finished undergoing a maintenance period it is scheduled for a new period, and the date assigned is checked for conflicts with other aircraft. When a resolvable conflict occurs, the simulation corrects the conflict by rescheduling the aircraft. The number of days that the aircraft's scheduled induction date is modified is then recorded as well as the fact that a reschedule was executed.

V. MODEL IMPLEMENTATION

A. SIMULATION SCENARIO

To gauge how well the simulation implements the ISIS rules a test scenario was created with three squadrons. At the start, one squadron was deployed. Another was scheduled to go on deployment, relieving the deployed squadron. The third squadron was not deployed. The deployed squadron was comprised of ten UIII aircraft. The squadron preparing to deploy had eight aircraft including two NUDs. The other non-deployed squadron also had eight aircraft, one was NUD. This scenario is summarized by Figure 10.

	Deployed	Deploying	At Home
1	UIII	UIII	UIII
2	UIII	UIII	UIII
3	UIII	UIII	UIII
4	UIII	UIII	UIII
5	UIII	UIII	UIII
6	UIII	UIII	UIII
7	UIII	NUD	UIII
8	UIII	NUD	NUD
9	UIII		
10	UIII		

Figure 10. Starting conditions for test scenario

For each run, starting conditions were established that located the NUD aircraft at specific positions within the respective squadron's maintenance cycle. Each run was planned to last for ten deployments.

To estimate how ISIS may work under a variety of scenarios, the positions of the NUD aircraft within the squadron's maintenance cycles were varied over all the potential

positions (See Figure 11). This meant that the two NUD aircraft in the deploying squadron (Squadron One) were moved throughout all of the positions within the maintenance cycle. For instance, in one case the NUD aircraft were in the first and second positions. Then they were moved to the first and third. This was done for all the possible positions within the cycle. Additionally, the position of the NUD aircraft in the other at home squadron (Squadron Two) was also changed over all of the positions within that squadron. Figure 11 illustrates the position of the NUD aircraft within each maintenance cycle for one case.

Squadron One	NUD One	**1**	2	3	4	5	6	7	8
	NUD Two	1	**2**	3	4	5	6	7	8
Squadron Two	NUD	1	2	3	**4**	5	6	7	8

Figure 11. Locations of NUD aircraft within the squadron maintenance cycles.

The darker boxes indicate the position of the NUD aircraft in the cycle. Because the NUD aircraft are removed from the squadron when a deployment occurs, this test determined how the position of the transferring aircraft effected the scheduling process.

B. SIMULATION OUTPUT AND ANALYSIS

Varying the position of the NUD aircraft within the non-deployed squadrons led to two hundred and thirty separate trial runs. Of these trial runs, fifty percent (114 out of 230) ended with irreconcilable scheduling conflicts that caused a termination of the simulation prior to the planned ten deployments. Program execution was terminated because a continuation would result in the failure to transfer an aircraft to a squadron, leading to an improper allocation of aircraft among the squadrons. A successful run was one that executed all ten deployments.

While half of the runs succeeded in executing the full ten deployments, in every case the rescheduling of aircraft was required. In every case it was necessary to bring an aircraft in early, or late, at some point.

The starting position of the NUD aircraft within the maintenance cycle had a definite effect upon the number of successful deployments the simulation was able to execute. By locating the NUD aircraft at certain points in the maintenance cycle, the number of deployments executed was reduced.

This can be verified by looking at the position of the single NUD aircraft in the second squadron. The aircraft was positioned in each possible position (one through eight) within the maintenance cycle. The percentage of all successful runs for each specific position of the NUD aircraft within the maintenance cycle is illustrated in Figure 12. It is apparent from the graph that when the NUD aircraft is located in the fourth position within the maintenance cycle, there is a pronounced decrease in the total number of successful runs. Investigation of this case failed to reveal any apparent cause for the reduced success. It is likely that the ISIS program is sensitive to the initial conditions of the run. This hypothesis is supported by the results of additional runs. When the composition of the squadrons was altered slightly, the program ran to completion without any reschedules. In some cases, locating an aircraft in the fourth position did not adversely effect the success of the runs. While an exhaustive test of all squadron compositions was not made, the sensitivity of the ISIS program to starting conditions was illustrated.

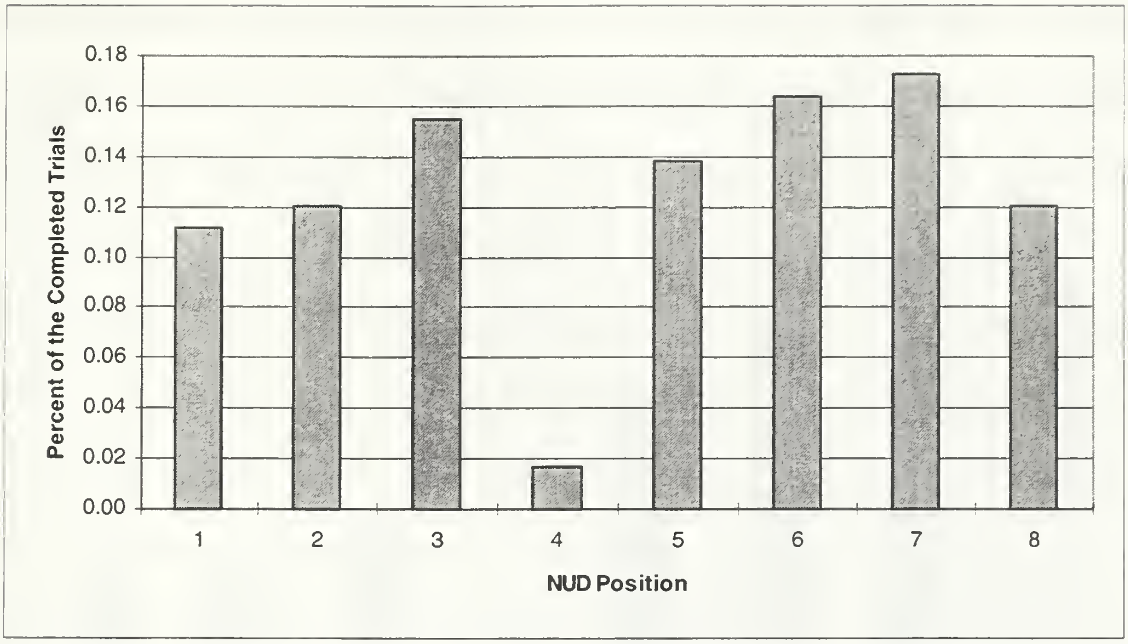

Figure 12. Percent of Completed Trials versus Second Squadron NUD Position

A similar, though less pronounced effect could be seen with the movement of the NUD aircraft in the first squadron. There is one less position listed (seven versus eight) for this analysis, since there would have been duplicate tests if the two NUD aircraft simply had their positions swapped. Figure 13 illustrates this situation.

Squadron One	NUD One	1	2	3	4
	NUD Two	1	2	3	4
Squadron Two	NUD	1	2	3	4

Squadron One	NUD One	1	2	3	4
	NUD Two	1	2	3	4
Squadron Two	NUD	1	2	3	4

Figure 13. Swapping NUD aircraft positions

Within Squadron One, whether NUD One enters maintenance first (left side) or NUD Two enters maintenance first (right side) is irrelevant, because the first two aircraft to enter maintenance are NUD aircraft.

Figures 14 and 15 show the percentage of successful runs with the first NUD aircraft in different locations, and the second NUD aircraft being moved. Once the

positions of the NUD aircraft in Squadron One were fixed, the NUD aircraft in Squadron Two was tested in each position, one through eight.

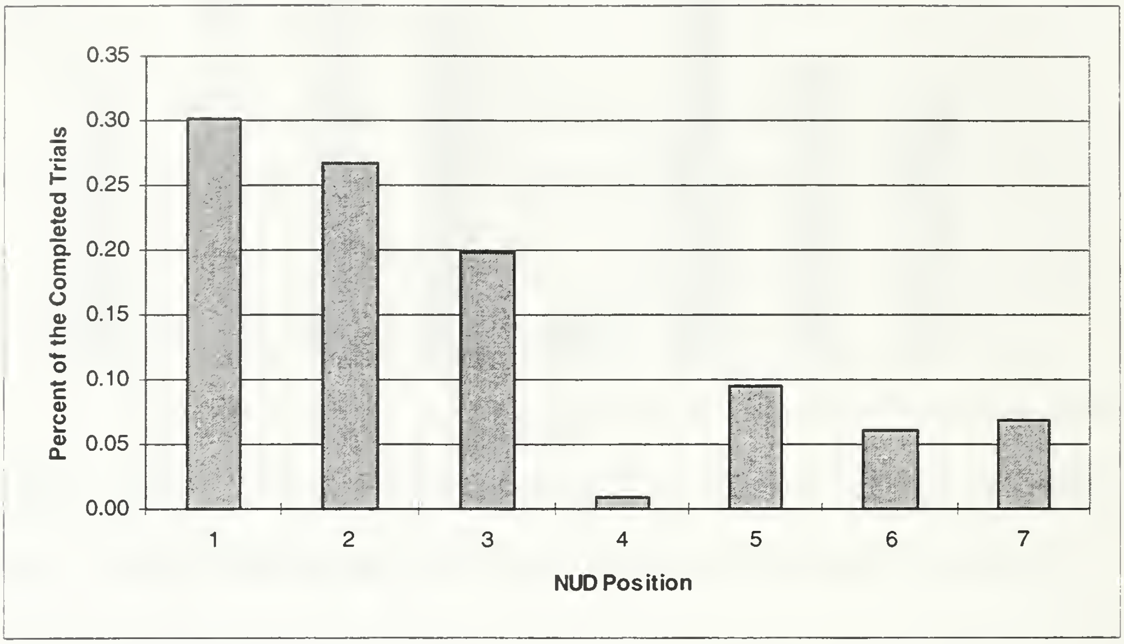

Figure 14. Squadron Two - NUD Aircraft One

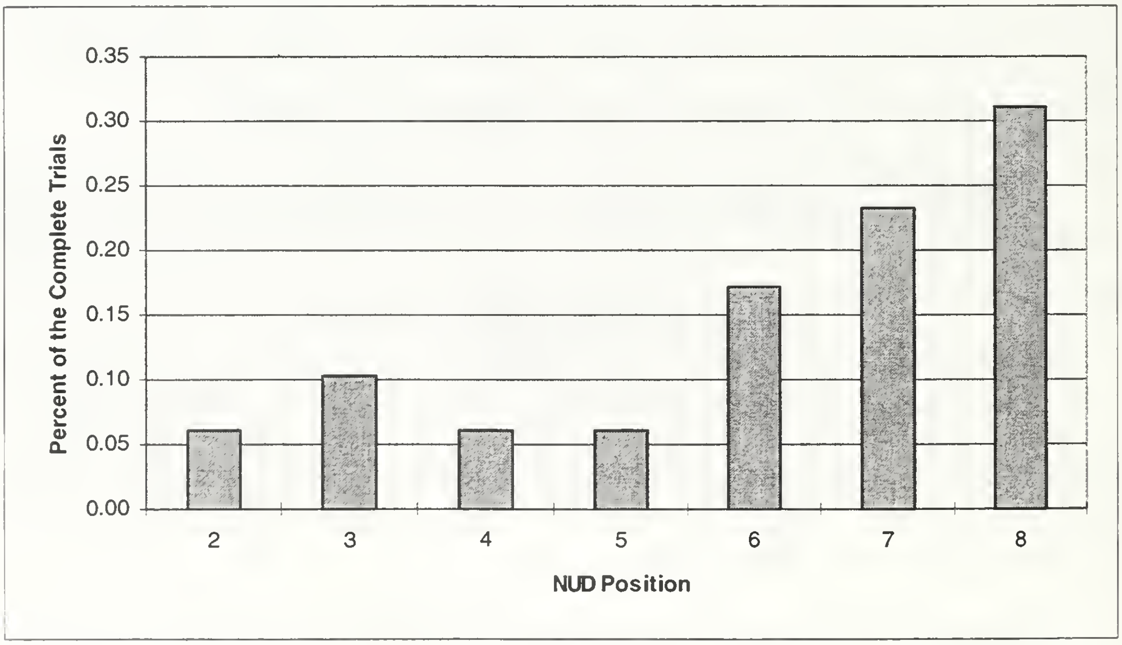

Figure 15. Squadron One - NUD Aircraft Two

Further examination of the position of both of the NUD aircraft within the first squadron shows that there were complete runs in twenty-five cases. A single case refers to one possible combination of NUD aircraft within the deploying squadron, i.e., first and third positions within the maintenance cycle. With the first (deploying) squadrons alignment set, the second squadron's aircraft position was modified over a possible eight position. This meant that for any one of the twenty-five cases, there was the possibility of a maximum of eight successful trials. Figure 16 shows the twenty-five results. NUD 1 and NUD 2 refer to the positions of the NUD aircraft within the deploying squadron. Successes are the number of times, out of eight possible, that the full ten deployments were completed.

NUD 1	NUD 2	Successes
7	8	7
6	8	3
6	7	4
5	8	2
5	7	2
5	6	7
4	5	1
3	8	7
3	7	7
3	6	5
3	5	2
3	4	1
2	8	7
2	7	7
2	6	5
2	5	2
2	4	3
2	3	6
1	8	7
1	7	7
1	6	3
1	5	2
1	4	3
1	3	6
1	2	7

Figure 16. Results from setting the position of the deploying squadron's NUD aircraft

There was no combination of NUD aircraft within the first squadron that resulted in a successful run for each position of the NUD within the second squadron. There were eight cases that achieved success in seven of the eight aircraft trial positions, as shown in Figure 17.

Squadron One	NUD One	7	3	3	2	2	1	1	1
	NUD Two	8	8	7	8	7	8	7	2

Figure 17. Squadron One NUD positions associated with seven successful runs

Of those eight cases, the position of the NUD aircraft within the second squadron that resulted in a failed run was the fourth position. Figures 14, 15, and 17 also reflect that the greatest successes occurred when the first aircraft was in position one, two or three and the second aircraft was in position seven or eight.

C. SENSITIVITY ANALYSIS

Additional runs were made to test the effect of changes in the number of aircraft assigned to the squadrons. The deployed squadron was reduced from ten to nine aircraft, and the other squadrons were increased from eight to nine aircraft, without changing the number of NUD aircraft assigned. This made an additional three weeks available for scheduling within the squadron that began the run deployed. Within the home squadrons, three weeks less time was now available for scheduling maintenance or adjusting the schedule. Running the simulation for several cases showed that it was now possible to execute all ten deployments without any need to reschedule aircraft. Due to time constraints not every possible case was analyzed. The test cases that were run demonstrated that reducing the number of aircraft in the deployed squadron had a significant positive effect on the overall execution of the ISIS program. Now it was

possible to get through all ten deployments without rescheduling an aircraft, whereas in the previous test, not one of the 230 cases produced that success.

This result is noteworthy in light of the increase in number of aircraft to the two squadrons at home. Increasing the number of aircraft in those squadrons would be expected to make scheduling more difficult, since there would be less free time available in the schedule.

Another case was run in which the squadrons all remained at nine aircraft. The at home squadron were each assigned two NUD aircraft. This increase by one to the total number of NUD aircraft was handled without any reschedules. Once again, not every case was tested, but the success of a few cases indicates that the scheduling process can succeed with these conditions.

D. DISCUSSION

The baseline simulation output and results of the sensitivity analysis provide an indication of the difficulty that can arise when trying to schedule aircraft within a constrained environment. The number of aircraft assigned to a squadron, and the number of NUD aircraft can have an influence upon the need to reschedule aircraft when transfers occur. Reducing the deployed squadron by one aircraft makes available sufficient time that the maintenance program is much more successful. It is also worth noting how the position of the NUD aircraft within the squadrons can also impact the need to perform reschedules.

It is important to consider the results in light of the simplifications that were made to the model. There were five significant simplifications recognized while developing

this simulation. Without these scheduling aircraft would be more troublesome. Even with the included simplifications, rescheduling of aircraft was frequently necessary.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS AND RECOMMENDATIONS

The results discussed in Chapter V demonstrate the difficulty that can be encountered when ISIS is implemented in the manner done with this simulation. Analysis of the model output reveals that the position of the NUD aircraft within the maintenance cycle has a definite effect upon the success of the ISIS program as executed with the simulation. The number of aircraft that the squadrons contain is another significant factor effecting the success of the ISIS program. For example, reducing the number of aircraft in the squadron by just a single plane makes enough time available to successfully execute the ISIS program more often. The composition of aircraft within a VP squadron fluctuates by number of aircraft and composition of update versions, this makes adhering to a program such as ISIS difficult.

While the implementation of the ISIS program by the USCS and RNLN is bringing the benefits expected, anticipating similar results for the U.S. Navy based on the results seen by those two organizations is unwise. The aircraft transfer issue is a significant one that constrains the optimal functioning of the ISIS program. Aircraft transfers could prove to be significant enough to jeopardize the expected benefits of ISIS.

B. FURTHER RESEARCH

This model is capable of providing insight into the relationship between the number and type of aircraft in a squadron and the number of times and degree to which scheduled maintenance will need to be adjusted. It also shows how the position of NUD

aircraft in a maintenance cycle can impact the overall success of the maintenance plan. However, the model as currently implemented does not address several issues that play into the success of a program such as ISIS. Research on the impact that pre-and post-deployment stand-downs would have on this maintenance plan is recommended. Additional consideration for PDM and other non-regular transfers is also needed to recreate the current operating environment more realistically. Site-specific aircraft required by a squadron as well as inter-Wing transfers are also significant issues. As the evaluation of the ISIS program by VP10 continues, information will become available regarding the length of time typically needed to inspect and repair an aircraft. This information can be used to adjust the fixed three-week maintenance period to more accurately reflect the period of time aircraft spend in maintenance. The modular design of the simulation model in this thesis will simplify incorporation of enhanced features developed by further research.

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APPENDIX A.

The following table is a sample of the output produced by the simulation after having grouped and sorted the data. The first column is the test trial number. The second and third columns show the position within the deploying squadron of the NUD aircraft. The fourth column is the position within the at-home squadron of the NUD aircraft. Number of deployments is the number of deployments completed when the simulation stopped. Ten deployments were scheduled for all of the trials. The remaining columns show the number of days that a reschedule was made for. Positive numbers represent scheduling an aircraft earlier than originally planned, and negative numbers represent scheduling an aircraft later than planned.

Tnal Number	1st Sqd/ AC One	1st Sqd/ AC Two	2nd Sqd	No. of Deployments													
1	1	5	1	5	114	70	21	21	1	1	1	1	-1	-1	-1	-1	-1
2	1	4	1	5	21	1	1	1	1	1	-1	-1	-1				
3	1	3	1	10	69	21	3	1	1	1	1	1	1	1	1	1	1
4	1	2	1	10	21	20	1	1	1	1	1	1	-1	-1	-1	-1	-1
5	1	6	1	10	21	3	1	1	1	1	1	1	1	1	1	1	1
6	1	7	1	10	21	3	1	1	1	1	1	1	1	1	1	-1	-1
7	1	8	1	10	43	26	25	21	21	1	1	1	1	1	1	1	1
8	2	8	1	10	190	48	22	22	21	1	1	1	1	1	1	-1	-1
9	2	7	1	10	190	22	21	1	1	1	1	1	1	-1	-1	-1	-1
10	2	6	1	8	190	97	21	1	1	1	1	-1	-1	-1	-1	-1	-70
11	2	5	1	5	118	94	21	1	1	1	1	-1	-1	-1	-1	-1	-1
12	2	4	1	10	120	70	26	22	22	21	20	1	1	1	1	-1	-1
13	2	3	1	10	146	46	26	22	22	21	20	1	1	1	1	1	-1
14	3	4	1	5	45	21	1	1	1	1	1	1	1	-1	-1	-1	-1
15	3	5	1	5	118	94	21	1	1	1	1	1	-1	-1	-1	-1	-1
16	3	6	1	8	190	97	21	1	1	1	1	1	1	1	1	-1	-1
17	3	7	1	10	190	21	21	1	1	1	1	1	1	1	1	1	-1
18	3	8	1	10	172	45	22	21	1	1	1	1	1	1	1	1	1
19	4	8	1	5	190	21	1	1	1	1	1	-1	-21				
20	4	7	1	5	190	21	21	1	1	1	1	1	-1	-1	-1	-46	
21	4	6	1	5	190	21	1	1	1	1	1	-1	-1	-1	-70		
22	4	5	1	5	118	94	21	1	1	1	1	-1	-1	-1	-1	-1	-1
23	5	6	1	10	163	121	118	94	53	50	21	20	16	15	1	1	1
24	5	7	1	5	118	94	21	1	1	1	1	1	-1	-1	-1	-1	-1
25	5	8	1	5	118	94	21	1	1	1	1	-1	-1	-1	-1	-1	
26	6	7	1	8	119	76	26	21	20	1	1	1	1	1	1	-1	-1
27	6	8	1	8	185	97	21	1	1	1	1	1	1	-1	-1	-1	-1
28	7	8	1	10	185	26	26	22	21	21	1	1	1	1	1	1	1
29	1	2	2	10	70	45	1	1	1	1	1	1	-1	-1	-1	-1	-2
30	1	3	2	10	146	45	43	26	21	20	4	1	1	1	1	1	1

APPENDIX B.

The following section details the linear programming formulation of the minimum cost network flow model developed in the OptimizePool class.

A. Indices

a	Aircraft available to choose from (a1, …, a10);
d, d′	Beginning date of maintenance period (a1, …, d100);
s	Source node;
t	Terminal node;

B. Data

D	End of planning horizon;
δ_{ad}	Deviation if aircraft a starts on day d;
R	Required number of aircraft;

C. Variables

X_{ad}	Indicates that aircraft a starts maintenance on day d;
Y_{sa}	Indicates whether aircraft a is selected;
Z_{dt}	Indicates whether beginning date d is selected;

D. Formulation

Objective Function

Minimize:

1. $$\sum_{a}\sum_{d}\delta_{ad}X_{ad}$$

Subject To:

2. $$\sum_{a} Y_{sa} = R$$

3. $$\sum_{d} Z_{dt} = R$$

4. $$\sum_{d} X_{ad} = Y_{sa} \qquad \forall a$$

5. $$\sum_{a} X_{ad} = Z_{dt} \qquad \forall d$$

6. $$\sum_{d'=d}^{\min of\ \{D, d+20\}} Z_{d't} \leq 1 \qquad \forall d$$

7. $$X_{ad}, Y_{sa}, Z_{dt} \in \{0,1\} \qquad \forall a, d$$

Discussion

1. Objective Function Explanation

The purpose of the model is to minimize the numbers of days that the selected aircraft deviate from their current induction dates. This is accomplished by determining by how many days each aircraft would deviate if it were to use any of the available maintenance periods. If an aircraft is selected for transfer, the number of days of deviation, for it's selected induction date, is added to the objective function. Aircraft are added until the requested numbers have been assigned.

Constraint Explanations

2. Aircraft Assigned from Source

This constraint ensures the number of aircraft assigned from the source node equals the number requested.

3. Aircraft Date Assignments

This ensures that the number of aircraft being assigned to maintenance periods is equal to the number of aircraft that have been requested.

4. Aircraft Node Flow Balance

This flow balance constraint ensures that the amount of flow exiting an aircraft node is equivalent to the amount entering the node.

5. Date Node Flow Balance

This constraint balances the flow into and then out of each date node. Ensures that no flow is lost in the network.

6. Aircraft Allowed

Prevents more than one aircraft from being assigned to a particular day for maintenance. Maintenance periods are broken into blocks of twenty-one days. This constraint ensures that no overlapping blocks have aircraft assigned to both.

7. Binary Variables

Ensures that the flow along any arcs in the network have a value of one or zero.

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